

NORTHERN GREAT PLAINS NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE NORTHERN GREAT PLAINS NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to -4.0 , a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. *Environmental Management*. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. *Atmospheric Environment* 31(11):1695-1708.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at www2.nature.nps.gov/ard/pubs/index.htm)

SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE NORTHERN GREAT PLAINS NETWORK

Park	Code	State	Risk	O3 Data
Agate Fossil Beds NM	AGFO	NB	low	kriged
Badlands NP	BADL	SD	low	kriged
Devils Tower NM	DETO	WY	low	kriged
Fort Laramie NHS	FOLA	WY	low	kriged
Fort Union Trading Post NHS	FOUS	ND	low	kriged
Jewel Cave NM	JECA	SD	low	kriged
Knife River Indian Village NHS	KNRI	ND	low	kriged
Missouri NNR	MNRR	SD	low	kriged
Mount Rushmore N MEM	MORU	SD	low	kriged
Niobrara NSR	NIOB	NB	low	kriged
Scotts Bluff NM	SCBL	NB	low	kriged
Theodore Roosevelt NP	THRO	ND	low	monitored
Wind Cave NP	WICA	SD	low	kriged

AGATE FOSSIL BEDS NATIONAL MONUMENT (AGFO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for AGFO					
	1995	1996	1997	1998	1999
Sum06	13	19	14	21	14
W126	18.9	25.8	20.9	34.2	24.4
N60	266	454	309	605	391
N80	19	21	13	53	20
N100	1	1	0	7	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at AGFO					
	1995	1996	1997	1998	1999
Month 1	4.89	1.94	-1.08	5.59	-1.85
Month 2	5.49	1.58	2.62	5.27	-1.01
Month 3	1.74	0.04	0.59	4.13	-1.68

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at AGFO					
	1995	1996	1997	1998	1999
April	1.59	0.38	-0.30	1.45	0.21
May	6.18	2.34	-1.08	5.59	-1.85
June	4.89	1.94	2.62	5.27	-1.01
July	5.49	1.58	0.59	4.13	-1.68
August	1.74	0.04	-0.60	0.14	0.24
September	-0.72	-0.64	-0.07	6.51	-1.44
October	-1.74	-0.29	-1.10	0.66	-1.32

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is generally below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than seven hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- The similar levels of ozone during the 90-day Sum06 accumulation periods and the infrequent occurrence of low soil moisture make it difficult to assess relationships between the levels of ozone and soil moisture. Three months of mild drought occurred in one year, and three years had favorable soil moisture. With this incidence and pattern of drought, it is not possible to determine whether a relationship exists between the level of soil moisture and the Sum06 index of exposure. There appears to be no relationship between the seasonal W126 index of exposure and soil moisture conditions. The highest ozone year, 1998, had favorable soil moisture, while the lowest exposure year, 1995, had one month of

mild drought. A middle ozone year, 1999, had five months of mild drought. There is no relationship between ozone and soil moisture in this pattern of drought.

The risk of foliar ozone injury at Agate Fossil Beds National Monument is low. The Sum06 threshold for injury is satisfied, but the Sum06 criteria are not. The N-value counts indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. Soil moisture levels are unrelated to the level of exposure and conditions in most years favor the uptake of ozone.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, skunkbush, and common snowberry.

BADLANDS NATIONAL PARK (BADL)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BADL					
	1995	1996	1997	1998	1999
Sum06	10	14	12	15	9
W126	16.0	21.4	18.8	28.5	18.0
N60	203	345	266	484	254
N80	14	15	10	39	10
N100	0	0	0	4	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BADL					
	1995	1996	1997	1998	1999
Month 1	3.16	-0.59	-2.19	-1.32	0.95
Month 2	-1.68	3.49	-1.92	-0.85	6.46
Month 3	7.19	-1.42	2.27	-1.33	0.67

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BADL					
	1995	1996	1997	1998	1999
April	0.87	-0.09	2.62	-1.48	0.95
May	3.16	0.09	-2.19	-1.32	6.46
June	-1.68	-0.59	-1.92	-0.85	0.67
July	7.19	3.49	2.27	-1.33	1.54
August	0.31	-1.42	-0.69	1.38	6.87
September	-0.85	0.67	0.61	-2.52	2.21
October	2.04	0.22	1.10	4.86	-0.86

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index marginally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show a few hours in which concentrations exceeded 80 ppb, and two years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations, when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The low and similar levels of exposure over the five-year period make it difficult to assess the relationship. There were two months of mild drought in 1998 the highest exposure year, and one month of mild drought in 1996 the second highest exposure year. In the years with mid-level exposures, there were two months of mild and moderate drought in 1997, and one month of mild drought in 1995. Soil moisture was normal in 1999, the lowest exposure

year. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is again not consistent. There were four months of mild and moderate drought in 1998 the year with the highest exposure, and one month of mild drought in 1996 the year with the second highest exposure. The two years with mid-level exposure had two months of mild and moderate drought in 1997, and normal conditions in 1999. There was one month of mild drought in 1995, the year with the lowest exposure.

The risk of foliar ozone injury at Badlands National Park is low. The thresholds for injury are marginally satisfied for the Sum06 index, but not satisfied for the W126 index of exposure. The N-value counts indicate there are limited exposures to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. The inverse relationship between exposure and soil moisture constrains the uptake of ozone at higher exposures and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use ponderosa pine or common snowberry.

DEVILS TOWER NATIONAL MONUMENT (DETO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

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Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for DETO					
	1995	1996	1997	1998	1999
Sum06	8	11	11	11	9
W126	15.4	21.1	20.0	29.9	20.1
N60	169	314	260	488	270
N80	10	10	7	27	6
N100	0	0	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

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Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at DETO					
	1995	1996	1997	1998	1999
Month 1	1.50	-2.47	3.57	-1.49	0.88
Month 2	6.04	-0.37	0.09	-2.74	4.13
Month 3	1.59	1.48	-1.40	2.33	-0.21

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at DETO					
	1995	1996	1997	1998	1999
April	1.50	1.06	3.57	-1.49	4.13
May	6.04	3.38	0.09	-2.74	-0.21
June	1.59	-2.47	-1.40	2.33	3.31
July	3.60	-0.37	4.26	1.15	2.60
August	2.36	1.48	0.17	2.14	2.74
September	0.07	-0.46	-0.60	0.85	0.69
October	5.40	2.52	0.05	9.06	-1.72

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is marginally satisfied. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- The low and consistent levels of exposure in the five-year period make it difficult to assess relationships between the 90-day Sum06 accumulation period indices of ozone and soil moisture. However, soil moisture levels associated with the Sum06 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The three years with the same, highest exposure index, 1996, 1997 and 1998, each had one or two months of mild or moderate drought. The two years with lower levels of

exposure, 1999 and 1995, had normal levels of soil moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. Only five months of drought occurred over the five-year period. There were two months of mild and moderate drought in the highest ozone year 1998. The three intermediate years had similar levels of exposure and one month of mild or moderate drought occurred in each. There were normal soil moisture conditions in the lowest exposure year, 1995.

The risk of foliar ozone injury at Devils Tower National Monument is low. The threshold levels for injury are marginally satisfied by the Sum06 index, but not by the W126 index. The N-value counts indicate there are few exposures to concentrations of ozone greater than 80 ppb, and exposure to 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, and skunkbush.

FORT LARAMIE NATIONAL HISTORIC SITE (FOLA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOLA					
	1995	1996	1997	1998	1999
Sum06	12	19	14	21	15
W126	20.0	27.8	22.2	35.4	25.8
N60	276	496	323	632	414
N80	18	19	12	49	18
N100	1	1	0	6	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOLA					
	1995	1996	1997	1998	1999
Month 1	0.21	-1.35	0.96	-0.94	-1.95
Month 2	7.25	0.03	1.17	0.46	4.11
Month 3	6.41	0.68	0.48	1.51	0.31

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOLA					
	1995	1996	1997	1998	1999
April	0.21	-0.21	0.96	-0.70	4.11
May	7.25	2.05	1.17	-0.94	0.31
June	6.41	-1.35	0.48	0.46	1.58
July	2.39	0.03	2.42	1.51	0.81
August	0.86	0.68	5.46	1.41	0.63
September	4.16	0.44	1.20	-1.30	3.32
October	1.65	0.72	2.30	6.70	-1.53

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than six hours in which the concentration exceeded 100 ppb, and most had only one hour. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Soil moisture levels during the 90-day and seasonal accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The risk of foliar ozone injury at Fort Laramie National Historic Site is low. The threshold levels for injury are satisfied by the Sum06, but not by the W126 index of

exposure. The N-value counts indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. Soil moisture levels are generally favorable for the uptake of ozone, although isolated months of mild drought occur.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use ponderosa pine or skunkbush.

FORT UNION TRADING POST NATIONAL HISTORIC SITE (FOUS)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOUS					
	1995	1996	1997	1998	1999
Sum06	1	1	5	1	1
W126	7.7	9.2	12.3	13.3	8.8
N60	32	61	139	147	54
N80	1	0	4	1	0
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOUS					
	1995	1996	1997	1998	1999
Month 1	0.92	-0.19	1.98	-2.54	-0.08
Month 2	3.21	0.98	-1.78	-1.85	6.77
Month 3	-2.09	-0.73	-2.39	1.16	0.47

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOUS					
	1995	1996	1997	1998	1999
April	0.92	0.04	1.98	-2.54	-0.08
May	3.21	1.12	-1.78	-1.85	6.77
June	-2.09	-0.19	-2.39	1.16	0.47
July	5.28	0.98	3.99	-1.20	0.62
August	2.25	-0.73	-1.37	-0.15	4.58
September	-0.52	1.46	-2.35	-2.18	1.87
October	0.06	0.04	-0.35	5.76	-0.90

Risk Analysis

- There are a few ozone-sensitive species at the site, however none of them are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations rarely exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years, and no relationships are apparent. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In each of the two highest ozone years, 1998 and 1997, there were four months of mild and moderate drought. In the three remaining years with

lower levels of ozone, there was one month of moderate drought.

The risk of foliar ozone injury at Fort Union Trading Post National Historic Site is low. The threshold levels for injury are not satisfied by either the Sum06 or W126 indices of exposure. The N-value counts indicate there are rare exposures to concentrations of ozone greater than 80 ppb, and no exposure to 100 ppb.

There are no bioindicators for ozone at the site.

JEWEL CAVE NATIONAL MONUMENT (JECA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias exaltata</i>	Tall milkweed	Asclepiadaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for JECA					
	1995	1996	1997	1998	1999
Sum06	8	13	10	14	10
W126	17.8	24.2	20.8	32.2	21.5
N60	226	404	295	560	318
N80	15	17	11	43	13
N100	0	1	0	5	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at JECA					
	1995	1996	1997	1998	1999
Month 1	6.17	-1.99	1.66	-0.81	2.81
Month 2	2.72	0.07	-0.92	4.14	-0.54
Month 3	2.63	3.99	5.81	2.45	3.50

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at JECA					
	1995	1996	1997	1998	1999
April	1.63	0.76	2.70	-1.45	2.81
May	6.17	3.79	1.66	-0.81	-0.54
June	2.72	-1.99	-0.92	4.14	3.50
July	2.63	0.07	5.81	2.45	0.32
August	0.03	3.99	2.58	4.47	3.67
September	0.67	1.88	1.03	2.09	0.46
October	4.16	6.49	0.69	8.42	-1.44

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than five hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Soil moisture levels during the 90-day and seasonal accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The low levels of ozone exposure at Jewel Cave National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels

for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and exposures above 100 ppb are rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, tall milkweed, ponderosa pine, quaking aspen, skunkbush, and common snowberry.

KNIFE RIVER INDIAN VILLAGE NATIONAL HISTORIC SITE (KNRI)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for KNRI					
	1995	1996	1997	1998	1999
Sum06	1	1	3	2	2
W126	6.3	7.1	9.0	10.4	6.5
N60	15	22	86	82	41
N80	0	0	0	0	1
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at KNRI					
	1995	1996	1997	1998	1999
Month 1	0.92	-0.19	1.98	-0.95	-0.16
Month 2	3.21	0.98	-1.78	-2.54	-0.08
Month 3	-2.09	-0.73	-2.39	-1.85	6.77

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at KNRI					
	1995	1996	1997	1998	1999
April	0.92	0.04	1.98	-2.54	-0.08
May	3.21	1.12	-1.78	-1.85	6.77
June	-2.09	-0.19	-2.39	1.16	0.47
July	5.28	0.98	3.99	-1.20	0.62
August	2.25	-0.73	-1.37	-0.15	4.58
September	-0.52	1.46	-2.35	-2.18	1.87
October	0.06	0.04	-0.35	5.76	-0.90

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show only one hour in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- The low levels of ozone during the 90-day Sum06 accumulation periods preclude assessing relationships between the levels of ozone and soil moisture. Relationships between the seasonal W126 index of exposure and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. However, soil moisture levels appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The highest ozone years, 1998 and 1997, each experienced four

months of mild and moderate drought. The three years with lower levels of ozone exposure experienced favorable soil moisture conditions with only one month of drought among them.

The risk of foliar ozone injury at Knife River Indian Village National Historic Site is low. The threshold levels for injury are not satisfied by either the Sum06 or W126 indices of exposure. The N-value counts indicate there was only one hour of exposure to concentrations of ozone greater than 80 ppb, and no exposure to 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, and quaking aspen.

MISSOURI NATIONAL RECREATION RIVER (MNRR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MNRR					
	1995	1996	1997	1998	1999
Sum06	2	1	4	3	5
W126	10.4	6.5	9.7	9.7	10.3
N60	149	69	136	133	137
N80	19	6	6	10	8
N100	2	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MNRR					
	1995	1996	1997	1998	1999
Month 1	4.84	-0.28	1.22	3.14	4.46
Month 2	-1.96	-1.13	-0.94	-1.50	0.29
Month 3	-1.14	3.33	-0.69	3.45	4.93

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MNRR					
	1995	1996	1997	1998	1999
April	3.32	-1.13	1.75	3.14	4.46
May	4.84	3.33	1.22	-1.50	0.29
June	-1.96	-0.75	-0.94	3.45	4.93
July	-1.14	1.47	-0.69	1.81	2.36
August	2.70	2.57	-0.85	3.32	0.15
September	2.45	2.17	0.87	-2.45	-1.87
October	2.92	-0.47	1.41	3.82	-1.78

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. Exposure indices were similar over the five-year period. The two highest exposure years, 1999 and 1997, had favorable soil moisture throughout, while the remaining three years each experienced one or two months of drought. Collectively, there is no relationship between the levels of ozone and soil moisture conditions. The seasonal W126 exposure indices were similar over the five-year period making it difficult to assess relationships between ozone exposure and soil moisture. However, soil moisture levels appear to be inversely related to ozone concentrations: when

ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. Years with the highest and second highest exposure indices, 1995 and 1999, each experienced two months of mild drought. Years with two slightly lower levels of exposure had either favorable conditions or two months of drought, while the lowest exposure year, 1996, had one month of mild drought.

The low levels of ozone exposure at Missouri National Recreation River make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. While there are some hours with concentrations of ozone above 80 ppb, the numbers are not high and concentrations of 100 ppb are rare. The apparent inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone and further reduces the likelihood that the exposures will produce foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, ponderosa pine, American elder, and common snowberry.

MOUNT RUSHMORE NATIONAL MEMORIAL (MORU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MORU					
	1995	1996	1997	1998	1999
Sum06	7	11	8	11	8
W126	17.0	22.9	20.1	30.6	19.8
N60	210	374	282	526	285
N80	14	16	11	40	11
N100	0	1	0	4	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MORU					
	1995	1996	1997	1998	1999
Month 1	6.17	-1.99	1.66	-0.81	2.81
Month 2	2.72	0.07	-0.92	4.14	-0.54
Month 3	2.63	3.99	5.81	2.45	3.50

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MORU					
	1995	1996	1997	1998	1999
April	1.63	0.76	2.70	-1.45	2.81
May	6.17	3.79	1.66	-0.81	-0.54
June	2.72	-1.99	-0.92	4.14	3.50
July	2.63	0.07	5.81	2.45	0.32
August	0.03	3.99	2.58	4.47	3.67
September	0.67	1.88	1.03	2.09	0.46
October	4.16	6.49	0.69	8.42	-1.44

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation, but some levels are marginal. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had four hours in which the concentration exceeded 100 ppb while the others had one or none. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Soil moisture levels during the 90-day and seasonal accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The low levels of ozone exposure and the relatively dry soil moisture conditions at Mount Rushmore National Memorial make the risk of foliar ozone injury to plants low. While

the Sum06 exposures marginally exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are only a few hours with concentrations of ozone above 80 ppb, and no year has more than four hours greater than 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, and common snowberry.

NIOBARA NATIONAL SCENIC RIVER (NIOB)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NIOB					
	1995	1996	1997	1998	1999
Sum06	2	1	4	3	5
W126	10.4	6.5	9.7	9.7	10.3
N60	149	69	136	133	137
N80	19	6	6	10	8
N100	2	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NIOB					
	1995	1996	1997	1998	1999
Month 1	7.22	-0.37	0.22	0.65	4.09
Month 2	0.20	-0.45	-0.77	0.26	0.51
Month 3	0.31	4.42	2.54	4.63	3.22

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NIOB					
	1995	1996	1997	1998	1999
April	5.00	-0.45	2.53	0.65	4.09
May	7.22	4.42	0.22	0.26	0.51
June	0.20	-1.28	-0.77	4.63	3.22
July	0.31	0.17	2.54	2.50	1.45
August	-0.23	1.58	1.13	1.75	-0.86
September	3.17	5.40	1.46	-1.16	1.50
October	4.41	0.72	3.84	5.12	-1.79

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods were normal and favored the uptake of ozone. There were no months of drought stress in the five-year assessment period. Relationships between the seasonal W126 index of exposure and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years and there were only three months of drought stress. There does not appear to be any association between the W126 levels of ozone and drought.

The low levels of ozone exposure at Niobrara National Scenic River make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. While there are some hours with concentrations of ozone above 80 ppb, the numbers are not high and concentrations of 100 ppb are rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, ponderosa pine, American elder, and common snowberry.

SCOTTS BLUFF NATIONAL MONUMENT (SCBL)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SCBL					
	1995	1996	1997	1998	1999
Sum06	13	18	13	20	14
W126	18.2	24.7	20.1	33.2	23.7
N60	259	431	300	585	380
N80	19	21	13	54	20
N100	1	1	0	7	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SCBL					
	1995	1996	1997	1998	1999
Month 1	2.56	-1.69	0.85	-1.67	-1.79
Month 2	5.38	0.56	1.61	0.47	4.74
Month 3	4.76	4.46	0.78	2.20	-0.17

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SCBL					
	1995	1996	1997	1998	1999
April	2.56	-0.83	0.85	-1.62	4.74
May	5.38	2.94	1.61	-1.67	-0.17
June	4.76	-1.69	0.78	0.47	2.73
July	2.56	0.56	1.75	2.20	2.03
August	1.61	4.46	1.67	0.58	2.16
September	1.03	3.76	-0.40	-1.58	4.01
October	2.89	0.81	2.96	6.50	-1.56

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had seven hours in which the concentration exceeded 100 ppb, but in most years there was one hour. These levels of exposure are not likely to injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because there were only three months of mild drought over the five-year period, and no association is apparent. Although there were only five months of mild drought during the W126 assessment period, soil moisture levels appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest ozone year, 1998, there were three months of mild drought, and one month in each of the

two next highest ozone years, 1996 and 1999. Soil moisture was favorable throughout the two lowest ozone years.

The low levels of ozone exposure at Scotts Bluff National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of hours of exposure with concentrations above 80 ppb, but exposure above 100 ppb is rare. In addition, drought in the higher exposure years constrains the uptake of ozone and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, ponderosa pine, skunkbush, and common snowberry.

THEODORE ROOSEVELT NATIONAL PARK (THRO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for THRO					
	1995	1996	1997	1998	1999
Sum06	1	2	10	1	-
W126	7.7	8.5	14.6	-	9.7
N60	19	30	178	-	25
N80	0	0	8	-	0
N100	0	0	0	-	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at THRO					
	1995	1996	1997	1998	1999
Month 1	0.77	-1.69	4.10	-2.19	-0.98
Month 2	5.04	0.37	-1.36	-2.11	0.08
Month 3	-1.74	-0.99	-1.85	2.59	3.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at THRO					
	1995	1996	1997	1998	1999
April	0.77	-0.57	4.10	-2.19	0.45
May	5.04	2.69	-1.36	-2.11	3.27
June	-1.74	-1.69	-1.85	2.59	-0.98
July	4.47	0.37	4.94	-1.29	0.08
August	4.32	-0.99	0.17	2.01	3.36
September	-1.19	2.89	-2.10	-0.86	1.97
October	0.40	-0.28	-0.36	7.46	-0.88

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- The low levels of ozone and one year of missing data make it difficult to assess relationships between the 90-day Sum06 accumulation period levels of ozone and soil moisture. Each year had one or two months of mild to moderate drought, and no relationships between ozone and soil moisture are evident. Although the seasonal W126 index of exposure shows greater range of values, one year of missing data makes it difficult to accurately assess relationships. The exposure index in 1997 was considerably greater than the other indices, and the year experienced three months of mild and moderate drought. The year with the lowest index, 1995, had two months of mild drought. The two intermediate years had favorable conditions and one month of mild drought. Overall, there is no clear relationship between ozone exposure and soil moisture conditions.

The low levels of ozone exposure at Theodore Roosevelt National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied, and in only one year did concentrations of ozone exceed 80 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, and common snowberry.

WIND CAVE NATIONAL PARK (WICA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WICA					
	1995	1996	1997	1998	1999
Sum06	9	14	10	15	10
W126	17.8	24.2	20.6	32.1	21.6
N60	231	408	295	560	324
N80	16	17	11	45	14
N100	0	1	0	5	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WICA					
	1995	1996	1997	1998	1999
Month 1	6.17	-1.99	1.66	-0.81	2.81
Month 2	2.72	0.07	-0.92	4.14	-0.54
Month 3	2.63	3.99	5.81	2.45	3.50

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WICA					
	1995	1996	1997	1998	1999
April	1.63	0.76	2.70	-1.45	2.81
May	6.17	3.79	1.66	-0.81	-0.54
June	2.72	-1.99	-0.92	4.14	3.50
July	2.63	0.07	5.81	2.45	0.32
August	0.03	3.99	2.58	4.47	3.67
September	0.67	1.88	1.03	2.09	0.46
October	4.16	6.49	0.69	8.42	-1.44

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than five hours in which the concentration exceeded 100 ppb, and two years had no hours. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Soil moisture levels during the 90-day and seasonal accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The low levels of ozone exposure at Wind Cave National Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of

hours of exposure with concentrations above 80 ppb, but exposure above 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, ponderosa pine, quaking aspen, skunkbush, and common snowberry.